STATUS REPORT

SR - 2

for

NASA GRANT NGR-14-005-032

entitled

INVISCID AND VISCID INTERACTION OF NON-ISOENERGETIC COMPRESSIBLE STREAMS IN EJECTORS AND THRUST AUGMENTATION SYSTEMS

for the period

July 1965 to July 1966

DEPARTMENT OF MECHANICAL AND INDUSTRIAL ENGINEERING
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I. RESEARCH PERFORMED

A. Analytical Work

1.0 Supersonic Axi-symmetric Ejector Program (Versions I, II)*

A comprehensive computer program for the analysis of supersonic ejector systems, based on the ejector flow model developed at the University of Illinois (Ref. 1, 2), has been completed. See Fig.1 for the basic ejector configuration treated.

A brief enumeration of the features and operational characteristics of the final version of the ejector program (II) is given in the following section.

1.1 Computer Program Features and Operational Characteristics

This program combines the various phases of the analysis of a supersonic ejector system which were formerly carried out by a time-consuming, combined computer-manual calculation procedure. Additional provisions, which were not formerly available, have been added for analyzing the mass flow characteristics as well as the flow field within ejector systems having "short" shrouds. The operation of this program for a typical case will now be described.

For a given set of input data, the following calculations are made:

i) The inviscid and viscid reduced mass flow characteristics versus secondary to primary stagnation pressure ratio are determined for the two principal operating regimes (primary stream wall impingement**, Fig. 2, and primary-secondary stream interaction, Fig. 1) of the ejector system.

ii) For the primary-secondary interaction regime, the mass flow characteristics are established by determining the sonic location in the secondary stream. There are two possible solution types

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* Version I of this program has been transmitted to:
Mr. Fred W. Steffen, Aerospace Engineer and Grant Monitor, NASA Lewis Research Center
Version II will be transmitted in the near future to Mr. Steffen.

** Perhaps some improvement for the special case where the secondary flow is zero could be obtained by incorporating the empirical method of Ref. 3 into the analysis. This would require only a minor modification to the present program.

depending on the ejector shroud wall length, viz., the ejector shroud length is such that the sonic location occurs at the ejector exit (Fig. 3) or that the sonic location occurs inside the ejector (Fig. 4). For the latter case, the flow field calculations are then continued downstream from the sonic location to the ejector exit. Depending on the ambient pressure at the ejector exit, the following downstream flow field configurations are possible: 1) subsonic flow to the exit, 2) supersonic flow to the exit*, or 3) supersonic-shock-subsonic flow to the exit**. Each of these downstream flow field configurations are calculated after the sonic location has been determined.

The ambient pressure that must be matched at the ejector exit for the particular downstream flow field solution, i.e., subsonic, supersonic, or supersonic-shock-subsonic, is determined. Based on each of these ambient pressure ratios and the particular ejector operating point, the thrust coefficient for the overall system is evaluated.

Thus, the static thrust performance of an air-augmented nozzle can be established throughout its operating range. This information, in conjunction with the methods proposed in Ref. 4, makes it possible to predict the installed in-flight performance of such an air-augmented nozzle.

1.2 Future Plans

A series of calculations, for several representative ejector geometries, are being carried out. The objectives are to establish the performance characteristics of these systems and to demonstrate the influence of the stagnation temperature ratio, specific heat ratios, and variations in ejector geometry on these performance characteristics. This calculation program will be concluded in the near future.

A final report dealing with the theoretical ejector program is in preparation.

2.0 Two Stream Turbulent Jet Mixing

Computer programs for the numerical integration of the equations governing the flow in the mixing region are being developed. The approach being followed is similar to that of Ref. 5 with the

* Reference 3 indicates, without discussion, this type of calculation in their Fig. 11.

** Reference 3 does not discuss this aspect of the influence of the ambient pressure on the "downstream" secondary flow field. However, this is a rather important point to be considered if an overall performance evaluation of such systems is to be made.

exceptions that the initial boundary layers are being considered and a more general form for the eddy diffusivity is being retained. Results of one aspect of this analysis will be dealt with in the forthcoming Ph. D. thesis of Ervin Bales, Department of Mechanical Engineering, University of Illinois.

2.1 Future Plans

Work in the development of programs for the calculation of the two-stream mixing zone will continue. Emphasis will be on the development of an expression for the eddy diffusivity, based on experimental data, which will improve the agreement between theory and experiment.

B. Experimental Work

1.0 Thrust Augmentation

The cold flow series of experiments (Tables I and II of the subject proposal) have essentially been completed. However, the hot flow experiments have not been performed as a result of the non-operational status of the high temperature air heater. This air heater is now operational and these remaining experiments will be conducted in September 1966.

2.0 Two-Stream Mixing

2.1 Two-Stream Mixing Facility

A complete series of cold flow experiments have been conducted to ascertain, by pitot probe measurements, the velocity profile and its development in the mixing zone. A portion of these results will be reported in the forthcoming Ph. D. thesis of Vernon Roan, Aeronautical and Astronautical Engineering Department, University of Illinois.

2.2 Interferometric Study of the Two Stream Mixing Zone

All of the optical components, after nearly ten months' delay, have been received. All other components for the interferometer have been fabricated and are ready for final assembly. The interferometer will be assembled, aligned, and checked out in late September and, as soon as possible, be utilized in the two-stream mixing investigation.

II. PUBLICATIONS

"Installed Performance of Air-Augmented Nozzles Based on Analytical Determination of Internal Ejector Characteristics," by H. H. Korst, A. L. Addy, and W. L. Chow. Presented at AIAA Propulsion Joint Specialist

Conference, Colorado Springs, Colorado, June 1965. Paper No. 65-596. A revision of this paper will appear in the September-October or November-December 1966 AIAA Journal of Aircraft.

III. PARTICIPATING PERSONNEL

Appendix A lists the faculty members and graduate students who have participated under this Grant.

IV. EXPENDITURES

Appendix B summarizes the current expenditures under this Grant.

V. REFERENCES

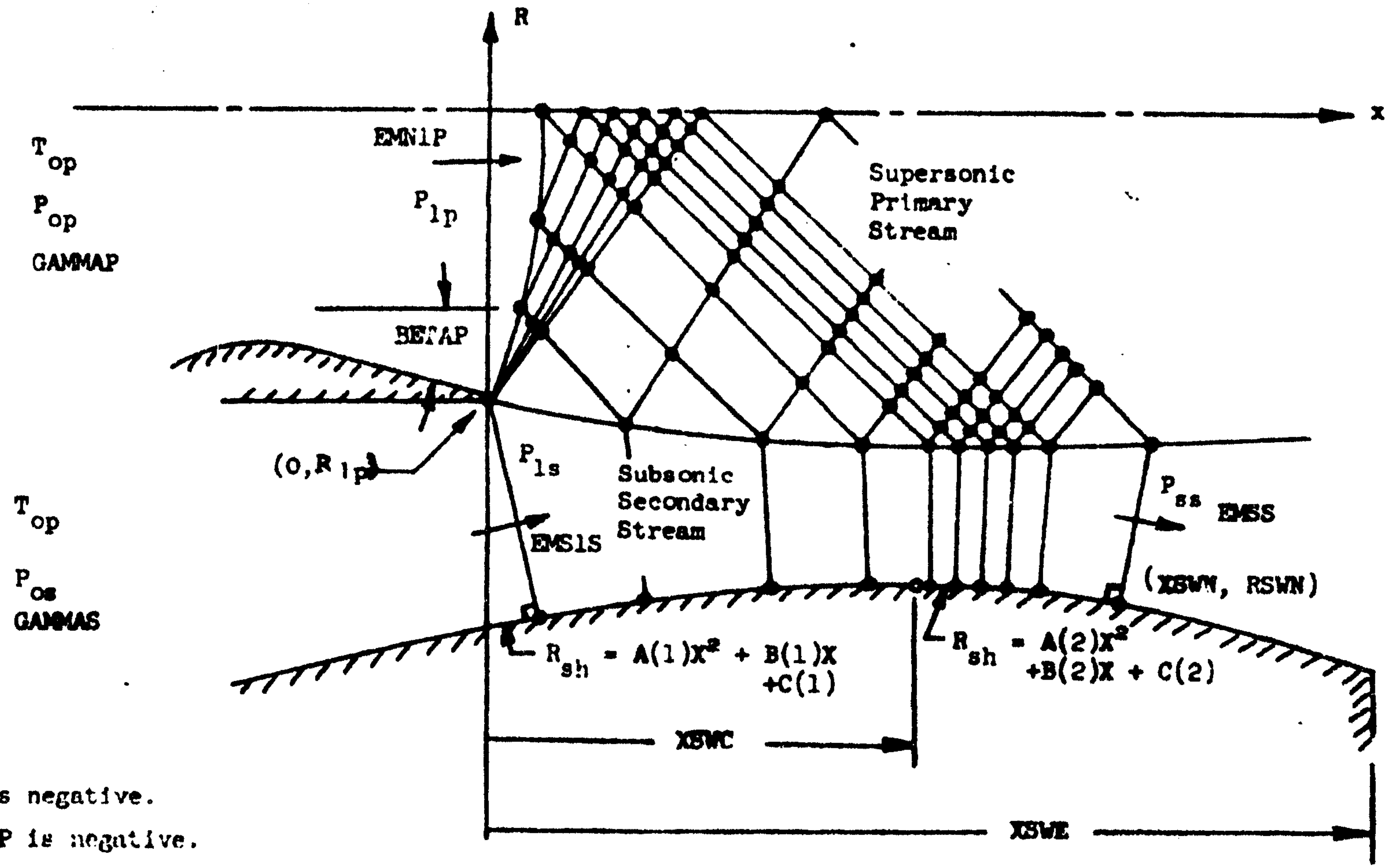
1. Chow, W. L. and Addy, A. L., "The Interaction Between the Primary and the Secondary Streams of Supersonic Ejector Systems and Their Performance Characteristics." AIAA Journal, April 1964.

2. Chow, W. L. and Yeh, P. S., "Characteristics of Supersonic Ejector Systems with Non-constant Area Shroud," AIAA Journal, Vol. 3, pp. 526-527.

3. Hardy, Jean-Marie and Delery, Jean, "Possibilitès Actuelles D'Étude Thèorique D'Une Tuyère Supersonique à Double Flux," presented at AGARD Propulsion Specialists Meeting, AEDC, Tullahoma, Tennessee, 25-28 October 1965.

4. Korst, H. H., Addy, A. L., and Chow, W. L., "Installed Performance of Air-augmented Nozzles Based on Analytical Determination of Internal Ejector Characteristics," AIAA Paper No. 65-596, AIAA Propulsion Joint Specialist Conference, Colorado Springs, Colorado, June 14-18, 1965. A revision of this paper is to be published in the September-October or November-December 1966 AIAA Journal of Aircraft.

5. Emmon, D. L., et al., "Investigation of Vehicle-Integrated Rocket Powerplants with Air Augmentation," Vol. 1 and 2, Final Report. Prepared for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Huntsville, Alabama, under Contract NAS 8-11017, by the Boeing Company, June 15, 1964 (Conf.).



NOTE: R_{1p} is negative.
BETAP is negative.

VERSION I Calculates only the subsonic flow field after the sonic location has been found

VERSION II - Calculates the subsonic, supersonic, and supersonic-shock-subsonic flow field after the sonic location has been found.

Figure 1 EJECTOR PROGRAM CALCULATION CONFIGURATION AND NOTATION

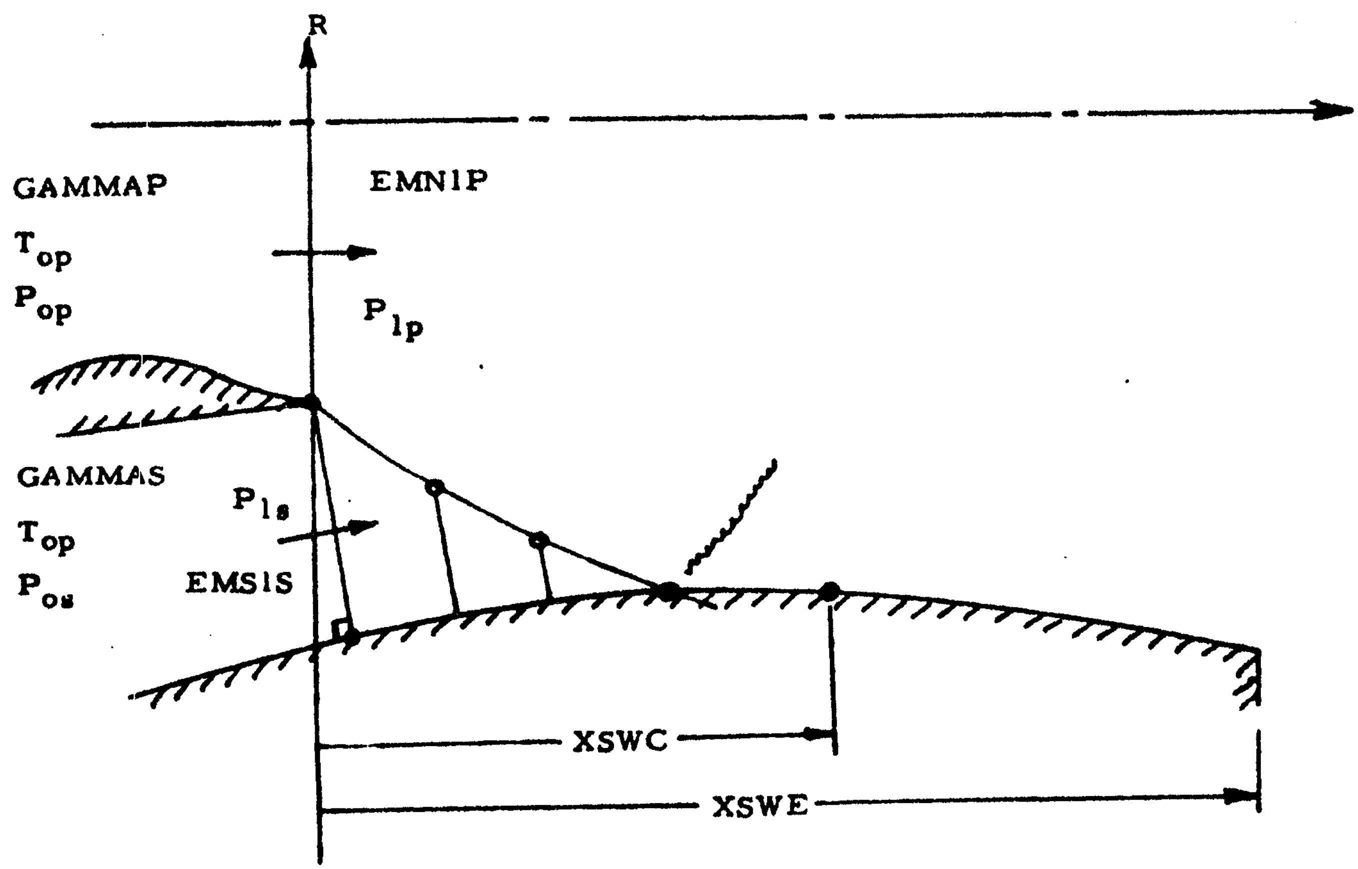


FIGURE 2. EJECTOR WALL IMPINGEMENT SOLUTION CONFIGURATION

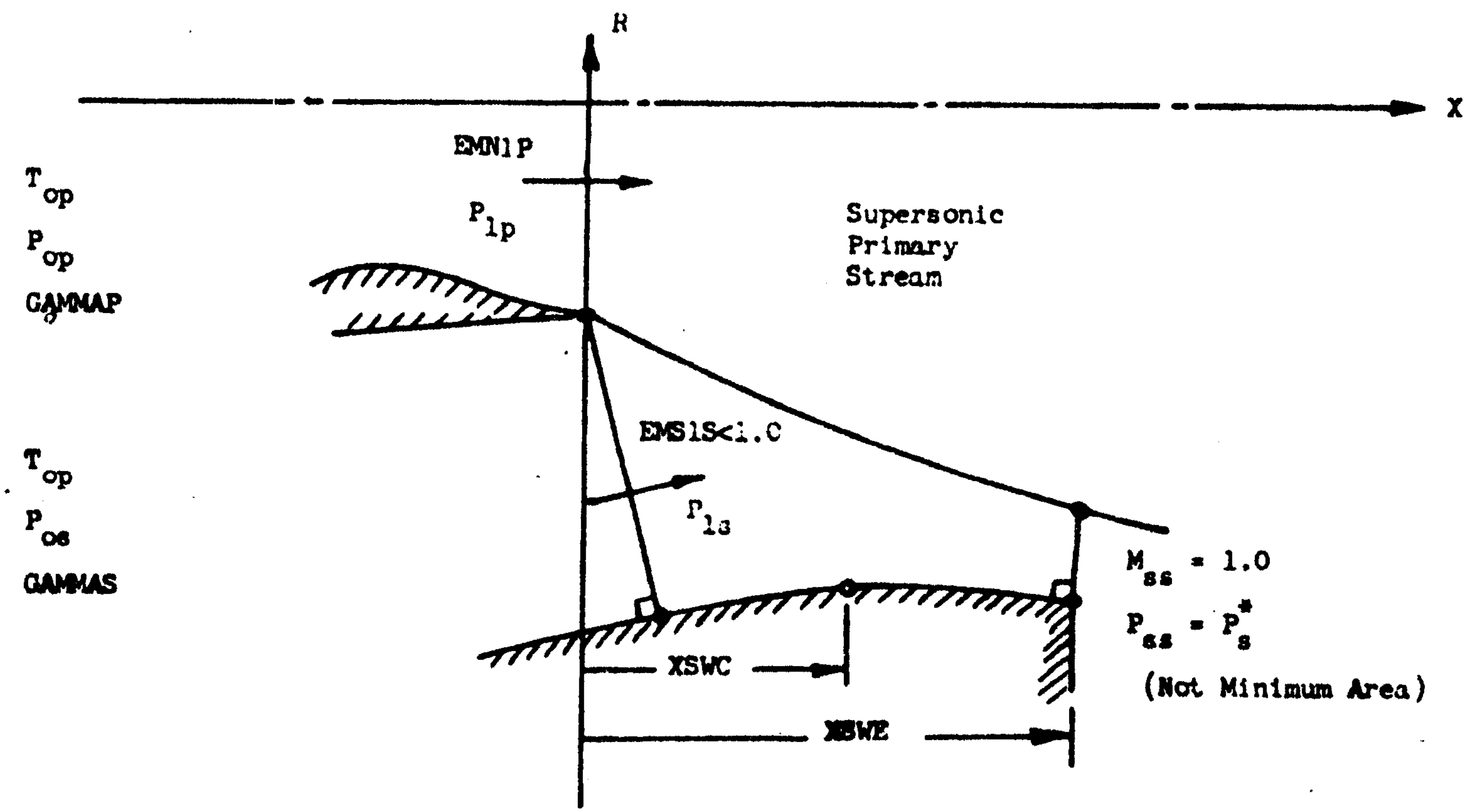


Figure 5 EJECTOR SHORT SHROUD EXIT SOLUTION

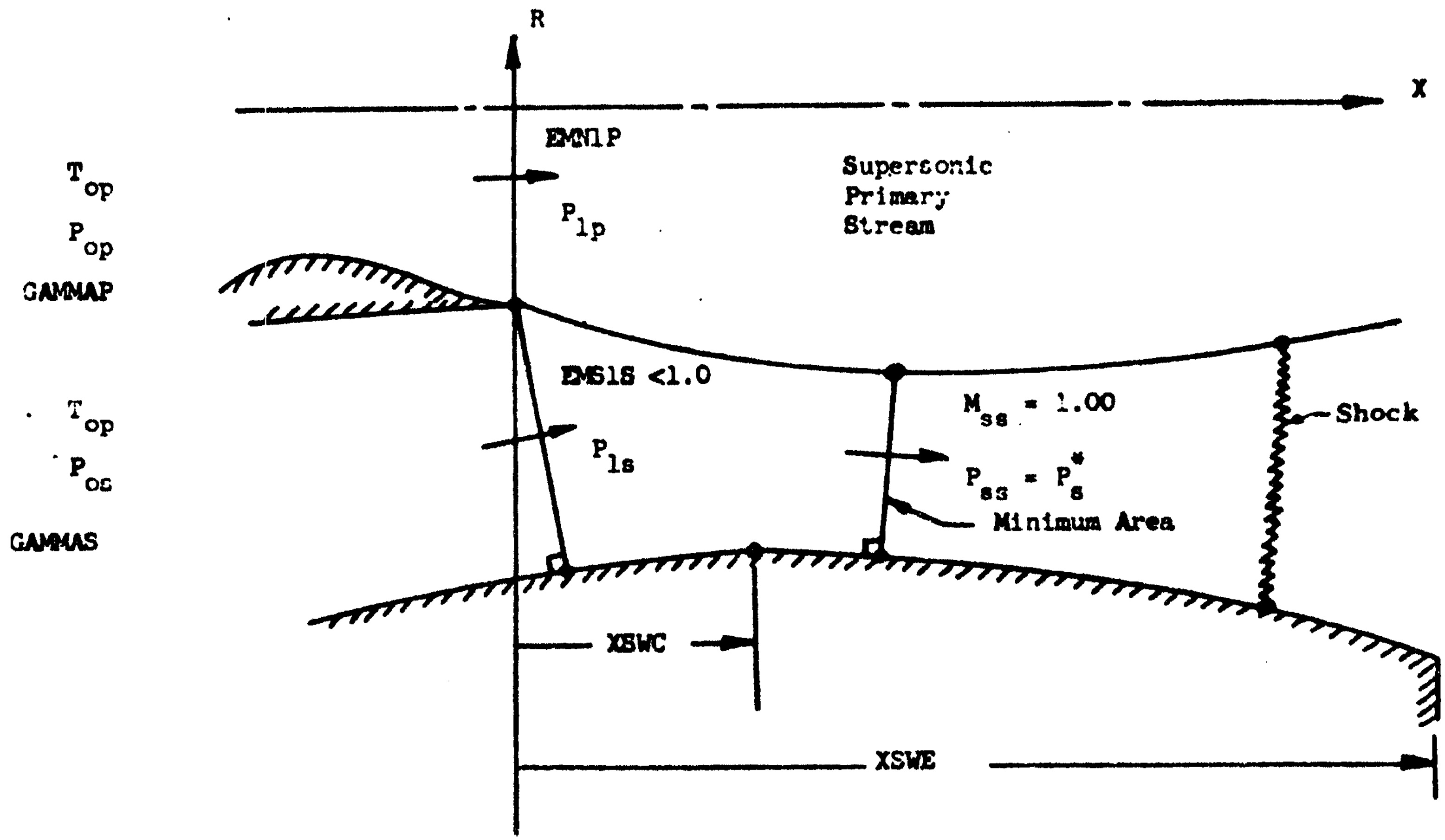


Figure 4. EJECTOR SONIC-MINIMUM AREA SOLUTION CONFIGURATION

APPENDIX A

LIST OF PARTICIPATING PERSONNEL

I.	Project Director:	Dr. Helmut H. Korst Professor of Mechanical Engineering and Head of the Department of Mechanical and Industrial Engineering (NO CHARGE)
II.	Consulting Scientist:	Dr. W. L. Chow Professor of Mechanical Engineering (NO CHARGE)
III.	Principal Investigator:	Dr. A. L. Addy Assistant Professor of Mechanical Engineering February 16 to June 1, 1966 - Half Time June 16 to August 15, 1966 - Half Time (NO CHARGE)
IV.	Research Assistants:	1) Vernon Roan Instructor and Ph. D. Candidate in Aeronautical and Astronautical Engineering (Formerly Senior Design Engineer and Group Leader, Pratt and Whitney - Florida Research and Development Center) 15 September 1965 to 15 June 1966 - NO CHARGE 16 June to 15 August 1966 - Half Time
		2) Robert Eilers Ph. D. Candidate in Mechanical Engineering (Received M. S. Degree, June 1963) 15 September 1965 to 15 June 1966 - Half Time 16 June to 15 August 1966 - Full Time
		3) Larry D. Howlett M. S. Candidate in Mechanical Engineering 15 September 1965 to 15 June 1966 - Half Time 16 June to 15 August 1966 - Full Time